N63-13909

NASr-21(05)

MEMORANDUM
RM-3536-NASA
MAY 1963

SOME SATELLITE ORBITS FOR THE WORLD MAGNETIC SURVEY

D. W. Stebbins

OTS PRICE

XEROX $ ______

MICROFILM $ ______

PREPARED FOR:
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

The RAND Corporation
SANTA MONICA • CALIFORNIA

NASr-21(05)

MEMORANDUM

RM-3536-NASA

MAY 1963

SOME SATELLITE ORBITS FOR THE WORLD MAGNETIC SURVEY

D. W. Stebbins

This research is sponsored by the National Aeronautics and Space Administration under Contract No. NASr-21. This report does not necessarily represent the views of the National Aeronautics and Space Administration.

The RAND Corporation

1700 MAIN ST. • SANTA MONICA • CALIFORNIA

PREFACE

A World Magnetic Survey is being planned by an international committee sponsored by the International Union of Geodesy and Geophysics, with E. H. Vestine of The RAND Corporation as chairman. The Committee has recommended that more than one satellite observing simultaneously, each in a different orbit, be used, a recommendation arrived at internationally with the assistance of COSPAR. This Memorandum reports the results of a brief study of possible orbits for these satellites. The work was undertaken for the National Aeronautics and Space Administration.

SUMMARY

This Memorandum considers the coverage of the magnetic field and particle belts around the earth that might be provided by several suitably instrumented satellites orbiting within a shell having an inner radius of approximately 6878 kilometers (500 km above the earth's surface) and an outer radius of approximately 14 earth radii. Within this shell probably occur most of the solar-induced variations in the magnetic field and particle populations. The following orbits are discussed in this report.

A satellite in a low polar orbit of radius approximately 6878 km provides good coverage of the earth near the earth's surface and thus closely supplements the surface measurements. Advantageously, it affords continuous observations and covers remote ocean areas as well as populous land areas.

A satellite in a much larger orbit (preferably at about ten earth radii but probably technology-limited to a few thousand kilometers above the earth's surface), operated in conjunction with the first satellite, would provide interesting observations on changes in either the magnetic field or the particle population occurring nearly simultaneously at different distances from the earth. During the course of the year this satellite would permit observations at some distance from the earth on both the sunlit and dark hemispheres for checking some interactions between the earth's magnetic field and the "solar wind."

A third satellite in a highly elliptic orbit covering the distances between a few thousand kilometers above the earth's surface and 12-14 earth radii above the surface will provide coverage in range. During the year, the apogee will occur at times on the sunlit side and at other times on the dark side of the earth. Thus further information on the interaction of the earth's magnetic field with the "solar wind" will be available.

A satellite in an elliptic orbit somewhat less eccentric than the one just described, coming within 500 km of the earth at perigee and going out to 6 or 7 earth radii at apogee, would provide a more rapid coverage over a range of altitudes that should include the storm ring

about the earth. Because of its shorter period this satellite would permit monitoring more rapid changes in the earth's environment than the previous one. At those times when it was in the plane of the ecliptic, it also would provide information on the shadow effect of the earth on the "solar wind."

A satellite in an even less elliptic orbit, for example, one which traveled between 700 km and one earth radius above the earth's surface, would permit rapid observations of the region of the inner Van Allen belt and the slot between the belts. Continuous observations of this region for a year should provide better understanding of it.

Finally, a satellite in an orbit similar to the one described in the preceding paragraph but oriented to pass over the poles of the earth would provide good information of the auroral region and the horns of the Van Allen belts. A combination of the last two satellites should permit excellent observations of the regions within one earth radius of the earth's surface. This continuous monitoring for a year would give us a far better understanding of the variations that occur in these regions than we have yet been able to obtain.

ACKNOWLEDGMENTS

It is a pleasure to acknowledge the assistance of E. H. Vestine and M. H. Davis, both of The RAND Corporation, in the preparation of this Memorandum.

CONTENTS

I. INTRODUCTION

The World Magnetic Survey (WMS) is a deferred item of the International Geophysical Year program. It is under the general international cognizance of the International Union of Geodesy and Geophysics (IUGG), to which the American Geophysical Union of the U.S. National Research Council adheres. The general technical aspects of the survey and its plans at the international level are the concern of the Committee on World Magnetic Survey and Magnetic Charts of the International Association of Geomagnetism and Aeronomy (IAGA) of the IUGG, with many nations as members.(1) The Committee, with E. H. Vestine as chairman and with the advice and assistance of many interested scientists, has prepared a Manual of Instructions for the survey.(2) In March, 1963, a new WMS Board was created by IAGA with an operative Secretariat to assist the enterprise.

The WMS includes magnetic measurements on land by survey parties in more than 50 nations. Magnetic surveys by airplane, mainly of ocean areas, are being undertaken by the Royal Canadian Air Force, by the U.S. Navy in Project Magnet; and surveys by Japan are being made. A survey by a non-magnetic ship is being conducted by the Soviet Union. Plans for magnetic surveys by earth satellite are less specific but some exploratory earth satellite data have already been obtained by the United States and the Soviet Union. It has been suggested that satellite-borne magnetometers monitor and measure the earth's magnetic field during the WMS of the International Year of the Quiet Sun (IQSY) and future years.

Magnetometer measurements have been made on Vanguard 3(3) and Explorer 10,(4) and contributions of rockets and satellites to the WMS have been considered.(5) The distant geomagnetic field has been observed by Pioneer 1.(6) Geomagnetic field measurements have also been made by some SU satellites.

This Memorandum considers only a few of the various advantages as well as disadvantages and limitations inherent in coverage by earth satellite, and many of these in only preliminary fashion. It leaves for future investigators the discussion of problems of instrumentation, storage, analysis, and charting of World Magnetic Survey data, though recognizing their importance.

In considering this satellite survey it is of interest first to review briefly the nature of the geomagnetic field. About 99 per cent of the geomagnetic field at ground level arises from within the earth. The remainder is due to external sources, such as the belts of charged particles trapped in the magnetic field of the earth. These external sources of the field undergo variations in intensity and spatial distribution.[7] Their intensity waxes and wanes during time intervals of a few hours to several days, as already shown by space probes.[6][8] Consequently, it has become increasingly apparent that magnetometers aboard satellites in appropriate orbits would offer an excellent means of making a broad and rapid survey of the main geomagnetic field and of the distributions of the external field in space and time.

It should be noted that both charged particles and fields need to be measured simultaneously in the plasma-rich regions of the ionsphere and above. At high levels plasma pressure gradients and plasma diamagnetism in the geomagnetic field are principal driving forces of electric currents producing transient magnetic fields in the magnetosphere. The fluctuating external boundary of the geomagnetic field, some earth-radii distant, should also be defined.

This Memorandum considers such factors of six possible satellite orbits as altitude, eccentricity, period, coverage of the earth's surface, orbital lifetime, orientation of the orbit plane, position of perigee in the plane, perturbations, and number of readings taken per year.

II. ORBITAL PERTURBATIONS

A few general comments may be in order concerning the behavior of satellite orbits about the earth. It is customary to describe any orbit in terms of the five parameters:* (1) semi-major axis, (2) eccentricity, (3) inclination to a reference plane through the earth's center (normally taken as the equatorial plane), (4) position of perigee in the plane, and (5) the position in a fixed reference plane of the ascending node where the satellite crosses the equatorial plane going from south to north.

The orbit plane of a satellite about a spherically symmetric attracting center subject to no perturbations from other nearby bodies will remain fixed in space; the shape and orientation of the orbit in the plane will not change. However, if the attracting center is not spherically symmetric (the earth has a bulge along the equator) and if there are other attracting bodies (the moon and the sun fulfill this condition), the satellite's motion is perturbed.

A complete analysis of such perturbed motion is not intended here, but a few general qualitative remarks are in order.

EARTH OBLATENESS EFFECTS

The two major perturbations are the retrograde precession of the orbit plane about the earth's axis and the change of perigee position in the orbit plane. These perturbations are centered about the earth's center and its axis of rotation. Both perturbations vary in the same way with changes in the semi-major axis and in eccentricity, becoming smaller as the semi-major axis increases and becoming larger as the eccentricity increases. (The eccentricity is zero for a circular orbit and is always less than unity for any closed orbit. Orbits with eccentricities greater than 0.9 are seldom considered.)

---

*For a complete description of the satellite in its orbit the angular position of the satellite from perigee at a particular time is also given but this parameter will not be used in this paper.

The nodal motion is a regression and is greatest for direct orbits near the equatorial plane. It decreases smoothly to zero for polar orbits, and becomes positive (the node advances) for orbits with inclinations greater than 90 deg.* For a circular orbit at an altitude of 500 km and an inclination of 98 deg, the node will advance at just the proper rate to keep the earth-sun line always in the orbit plane (if lunar and solar perturbations are neglected). Perigee advances at the greatest rate (about 15 deg per day at a 500 km altitude) for orbits in the equatorial plane. The rate decreases smoothly to zero when the inclination to the equator is 63-1/2 deg and then the motion changes direction and perigee regresses at an ever increasing rate to about 4 deg per day (for the above orbit) as the inclination increases to 90 deg.

LUNAR AND SOLAR EFFECTS

One of the effects of the moon and the sun is somewhat analogous to that of oblateness if one imagines these bodies smeared into rings of mass at their respective distances from the earth, the rings being similar in their effect to the equatorial bulge. For orbits within a few thousand kilometers of the earth's surface, the effect of oblateness predominates. As the orbital altitude increases (or the semi-major axis increases for elliptic orbits), the effect of oblateness decreases while the perturbations from the sun and the moon increase, until at about seven earth radii, the precessions from the two causes are equal, and such as to produce a precessional period of about 100 years. One difference is that precession from oblateness is about the earth's axis of rotation while the precessions from the moon and from the sun are about the normals to their respective planes of motion.

Other, more complicated perturbations that can be easily calculated only with the aid of electronic computers result from the moon and the sun. Such computations have been done by Space Technology Laboratories[9] for an Eccentric Geophysical Observatory (EGO) satellite for launches occurring every two hours in a 24-hour period. An interesting result

*The inclination is the angle between the eastward direction along the equator and the velocity vector of the satellite at the ascending node.

is that for some of the launches the perigee altitude decreases so that the satellite expires in the atmosphere in from 30 to 120 days; for other launches the perigee altitude increases rather regularly for the duration of the problem (two years), and only for a satellite launched within a few minutes of a critical time does the perigee distance oscillate with a more or less fixed amplitude about a nearly constant height for a period as long as a year. These extreme perturbations are largely the accumulation of the secular effect of the solar influence. They become more pronounced as both the semi-major axis and the eccentricity increase and are very sensitive to the initial orientation of the orbit plane.

From the above discussion it appears that any orbit proposed for the World Magnetic Survey will be subject to the perturbative effects of the moon, the sun, and earth's oblateness.* Such perturbations are discussed qualitatively as each orbit is considered in turn.

The earth's magnetic field, "fastened" to the rotating earth but not aligned along the earth's rotation axis, does not maintain a fixed orientation in space. Rather, the geomagnetic axis precesses about the earth's axis with each earth rotation. There is no way to put a satellite in orbit within a few thousand kilometers of the earth's surface and have the orbit plane maintain a more or less fixed orientation with respect to the geomagnetic axis. Hence, whereas a satellite when at perigee, say, will be at the same <u>geographic</u> latitude on successive revolutions (except as modified by perturbations), it will be observing at quite different <u>geomagnetic</u> latitudes on successive revolutions.

In the next section the effects of these perturbations on six specific satellite orbits are discussed as well as other features of the orbital motion of importance to the WMS.

---

*Actually, each of the planets has an effect, but it is so small that it can be neglected during a year for the orbits discussed here.

III. MAGNETIC SURVEY COVERAGE FOR VARIOUS SATELLITE ORBITS

POLAR CIRCULAR ORBIT NEAR RADIUS 6878 km (500 km)*

First to be considered is a polar circular orbit of radius 6878 km (500 km).

To achieve an orbital lifetime of a year, the radius should be at least 6878 km, based on present experience.

The period of such a satellite will vary from 94.7 to 96.7 minutes as the altitude above the earth varies from 6898 (520) to 6990 (612) km respectively.

At 6898 km, corresponding equatorial passes in the same direction will occur about 400 km east of those of the previous day, while at 6990 km they will occur about 400 km west. At an altitude corresponding to a period of 95.7 minutes, equatorial passes will occur at the same longitude on successive days. Hence, if complete coverage in longitude at selected intervals of a few hundred km along the equator is desired, the satellite altitude must be accurate within a few kilometers.

Because of the low satellite altitude and the small orbital eccentricity, perturbations from the sun and the moon will be practically negligible during a year.

For a circular orbit, there is no perigee, and there will be no regression of the nodes for a polar orbit. Thus the orbital plane will remain fixed in space as the earth moves about the sun. At one time the orbital plane will contain the earth-sun line; three months later it will be normal to this line, etc.

---

*Throughout this report the orbit is described as follows: for circular orbits, the length of the radius, and for elliptical orbits, the length of the radius vector to perigee, which is termed "perigee distance." Either kilometers or earth equatorial radii (a_e) are used, depending on the size of the orbit. Since, for satellites within a few hundred kilometers of the earth's surface, it is perhaps easier to visualize the altitude above the earth rather than the perigee distance, this altitude is given in parentheses after the perigee distance. In all cases the altitude at perigee is obtained by subtracting the earth's equatorial radius (6378 km) from the perigee distance. The answer so obtained will represent the actual height of perigee when the latter occurs over the equator, but, because of the earth's oblateness, it will become progressively less than the true height as the latitude of perigee increases, being 21 kilometers less at the poles.

If selected magnetic data are quoted at points every 100 km along the orbital path, as has been suggested by the Committee, a total of 2.4 million readings will be taken in a year, or one every 13.1 seconds.

The United States currently has plans to launch in 1964 the Polar Orbiting Geophysical Observatory, called POGO, which will have approximately these orbital parameters. It will measure many geophysical quantities in addition to scalar values of the total magnetic intensity. The Committee of the WMS has recommended that the data obtained from it be made available to interested scientists throughout the world through the World Data Centers established during the IGY.

POLAR CIRCULAR ORBIT AT RADIUS 10 a_e (9 a_e ALTITUDE)

The second orbit to be considered is a polar circular orbit with a radius of ten earth-radii.

The Committee has tentatively suggested that it would be desirable to have a satellite in such an orbit. It will not be possible by the time of the IQSY to achieve a circular orbit of this radius with the payload necessary for the desired instrumentation. Although the quantitative remarks in the rest of this section pertain to an orbit of this radius, corresponding remarks could be made for an orbit of the maximum radius that could be achieved for a polar orbiter by the time of the IQSY. (This maximum is likely to be considerably less than 10 earth-radii, and for practical reasons, more likely to be only a thousand kilometers or less above the earth's surface.) Figure 1 shows that an orbit at 10 earth-radii would enclose what is currently believed to be the major portion of the geomagnetic field as well as most of the particles trapped in the field.

At this altitude the geomagnetic field is weak, not very rigid, and can be altered rather easily by solar influences. The trapped radiation belts here can be easily influenced by solar activity, too. Hence, a satellite operating continuously at this altitude for a year should provide valuable information on the interactions among solar activity, the geomagnetic field, and the trapped particles. The solar output should be monitored continuously, also.

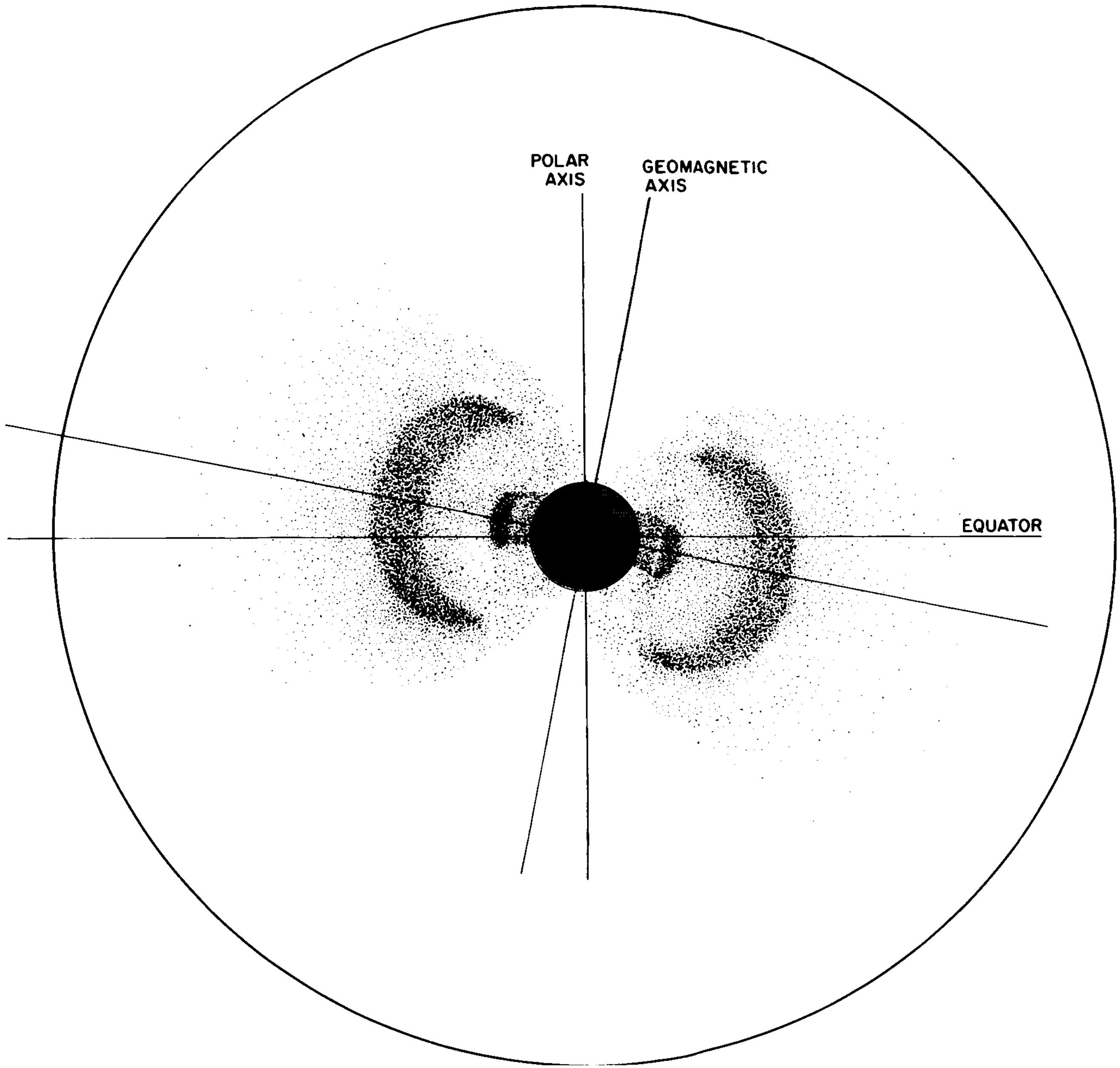

Fig. 1--Earth and radiation belts within a circular polar orbit with radius of ten earth-radii

If the satellite is launched with the orbital plane perpendicular to the ecliptic and containing the earth-sun line, information will be obtained on the amount of "compression" of the earth's field on the side toward the sun and the amount of "stretching" of the field in the lee of the earth as seen from the sun. Three months later, when the orbital plane is perpendicular to the earth-sun line, information on possible east-west asymmetries as measured in earth-sun longitude would be available as shown in Fig. 2.

At a radius of 10 earth radii the period would be 44.5 hr. In one satellite revolution the equator will advance 74,298 km or 5856 km less than two full circumferences. Hence the successive transits in the same direction progress eastward around the earth. After three and one-half satellite revolutions the traces begin to occur at positions 915 km east of similar traces during the preceding three and one-half revolutions. By the end of the twenty-fifth revolution the earth will be completely covered on a 915 km maximum equatorial interval. This will require 46.4 days. With each new revolution another complete survey of the earth on a 915 km interval will be completed.

If data are taken at the same angular separation along the orbit as for the "500 km" satellite, there will be 432 readings per revolution. This would represent 86,000 readings per year, or one every 6.1 minutes. Although readings at this rate would be made at angular intervals small enough to provide good coverage of the earth, it may be desirable to take them more frequently in order to detect significant changes in conditions occurring in less than six minutes.

There is no question that the orbiting lifetime of such a satellite will exceed a year.

HIGHLY ELLIPTIC ORBIT (PERIGEE 1.5 a_e, APOGEE 15 a_e)

Each of the previously described orbits will provide more or less continuous information on the conditions at a fixed distance from the earth for a period of a year. To provide information on conditions at different distances from the earth a satellite in an elliptical

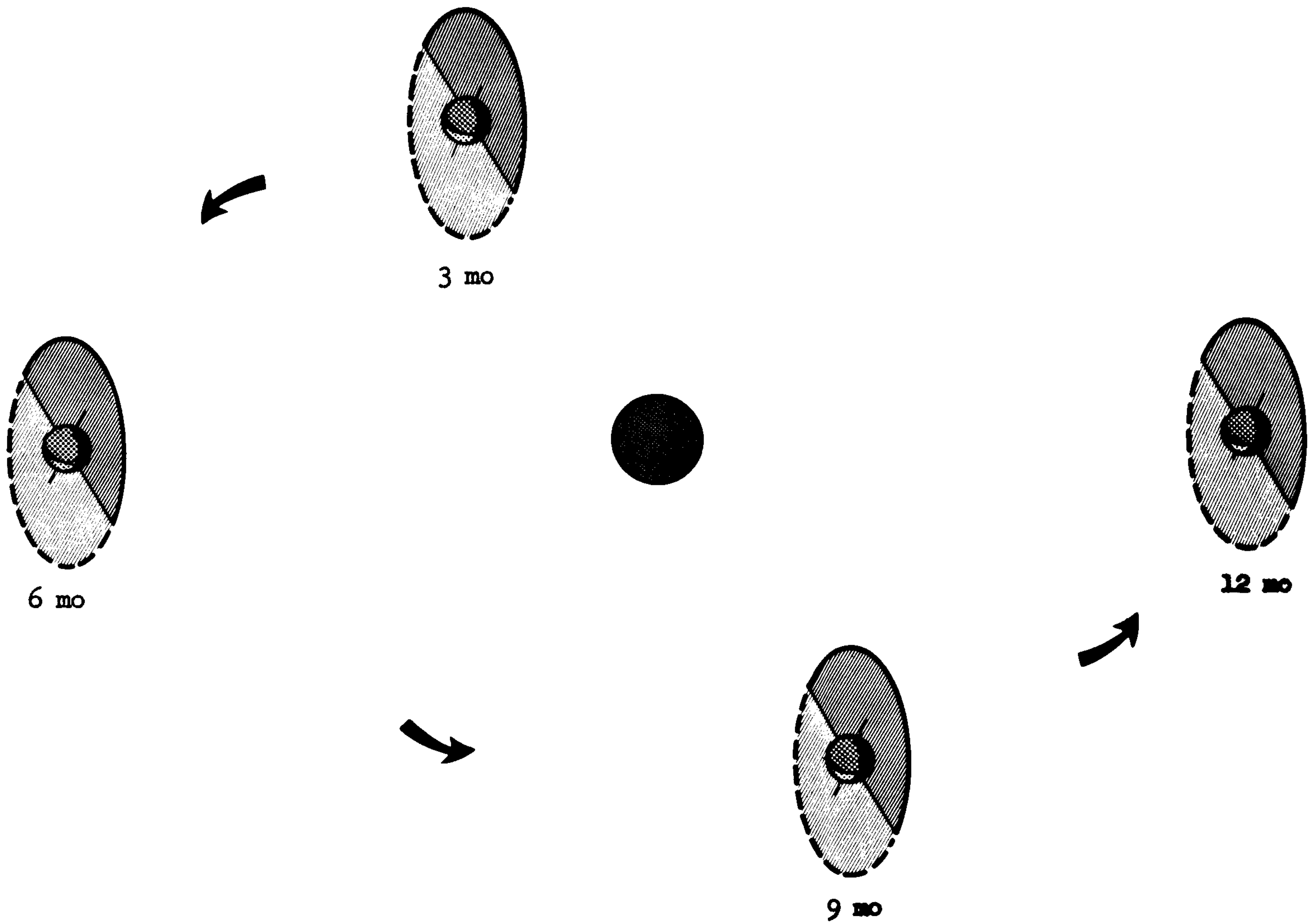

Fig. 2--Orientation of the $10\ a_e$ polar orbit with respect to the sun at 3, 6, 9, and 12 months after being launched perpendicular to the ecliptic with the orbit plane normal to the earth-sun line at launch. The initial position is not indicated but is the same as the 12-month position. Only perturbations from oblateness are considered.

orbit is desirable. The Committee has proposed that a satellite be placed in elliptical orbit with a perigee distance of 1.5 earth radii and an apogee distance of 15 earth radii. A satellite in this third orbit would pass through many of the interesting belts surrounding the earth, as shown in Fig. 3. Just what regions would be sampled most would depend on the orientation of the orbital plane and the position of perigee in the plane.

There appears to be no orientation that has all the advantages and none of the disadvantages. What promises to be an effective orientation is in the plane of the ecliptic, or nearly so. As pointed out in Sec. II, the effects of oblateness, the moon, and the sun will cause the orbit plane to precess so that its orientation in space will be continually changing. The amount of the perturbation due to oblateness has been calculated for a year and the orientation of the orbit in respect to the ecliptic at 3, 6, 9, and 12 months after being launched into the ecliptic plane is shown in Fig. 4. With this orientation, as the satellite moves in the orbit, it will pass from beneath the inner Van Allen belt through the belt, through the "slot" between the belts, through the outer Van Allen belt and on beyond the "storm belt." Thus data will be taken throughout the regions where it is now known that variations in the earth's field and in the particle and cosmic ray population occur.

The United States plans to launch an Eccentric (Orbiting) Geophysical Observatory (EGO) into a similar orbit in 1963.

Other orbits that appear promising for the WMS include one that would achieve rapid sampling of data from each of the Van Allen belts as well as the outer "storm belt" at about 5 to 12 earth radii from the center of the earth. The short time scale is desired to permit recording rather rapid changes following solar flares--changes occurring during a few hours. Sampling from regions both near and remote from the earth is desired to permit observation of possible relationships between effects in the different regions. A satellite in an elliptic orbit with a perigee altitude beneath the lower Van Allen belt and an apogee altitude that would put the satellite past the maximum of the storm ring provides a reasonable compromise. The position of the storm

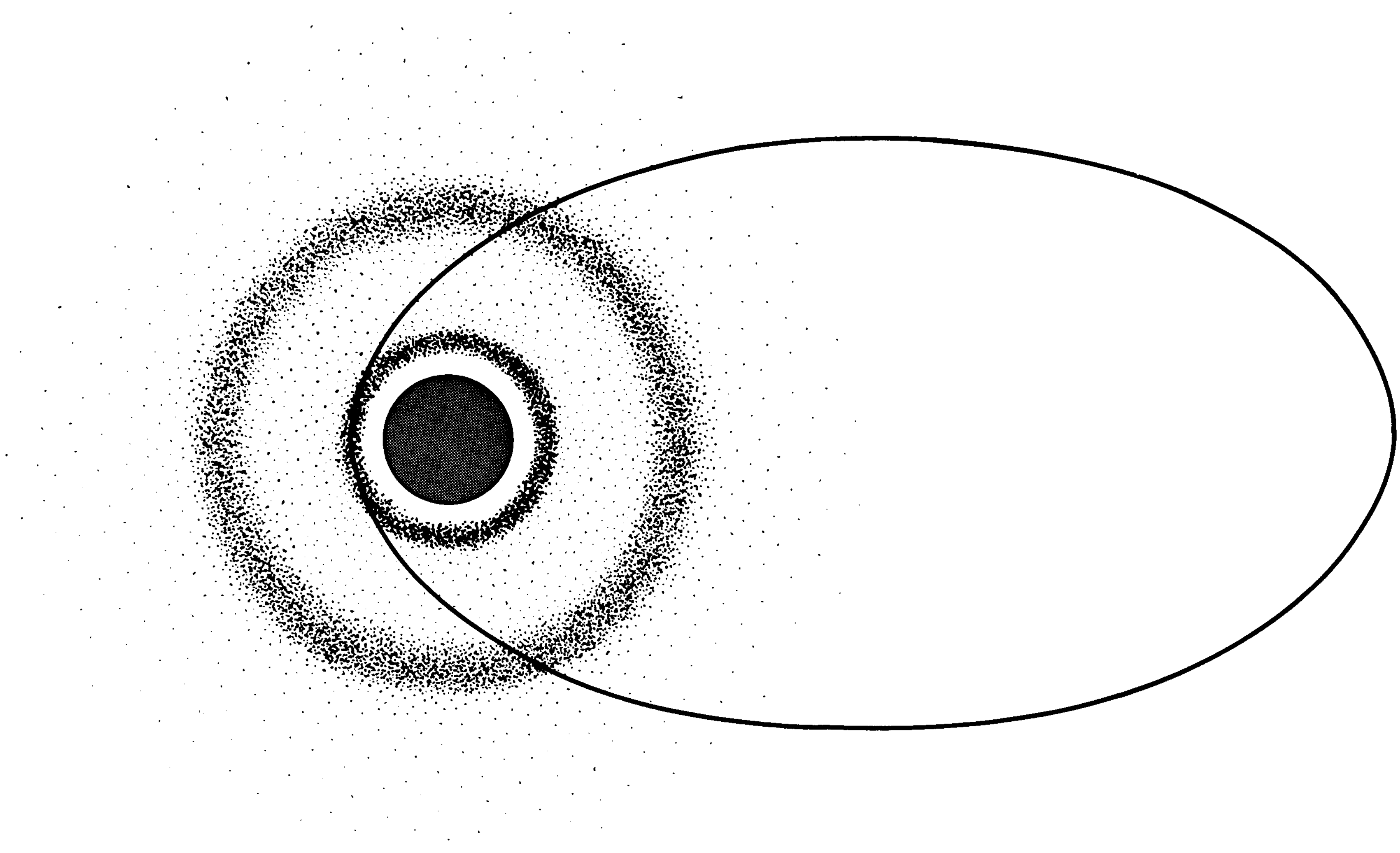

Fig. 3--Manner in which 1.5 $a_e/15\ a_e$ orbit in ecliptic plane passes through belts about the earth

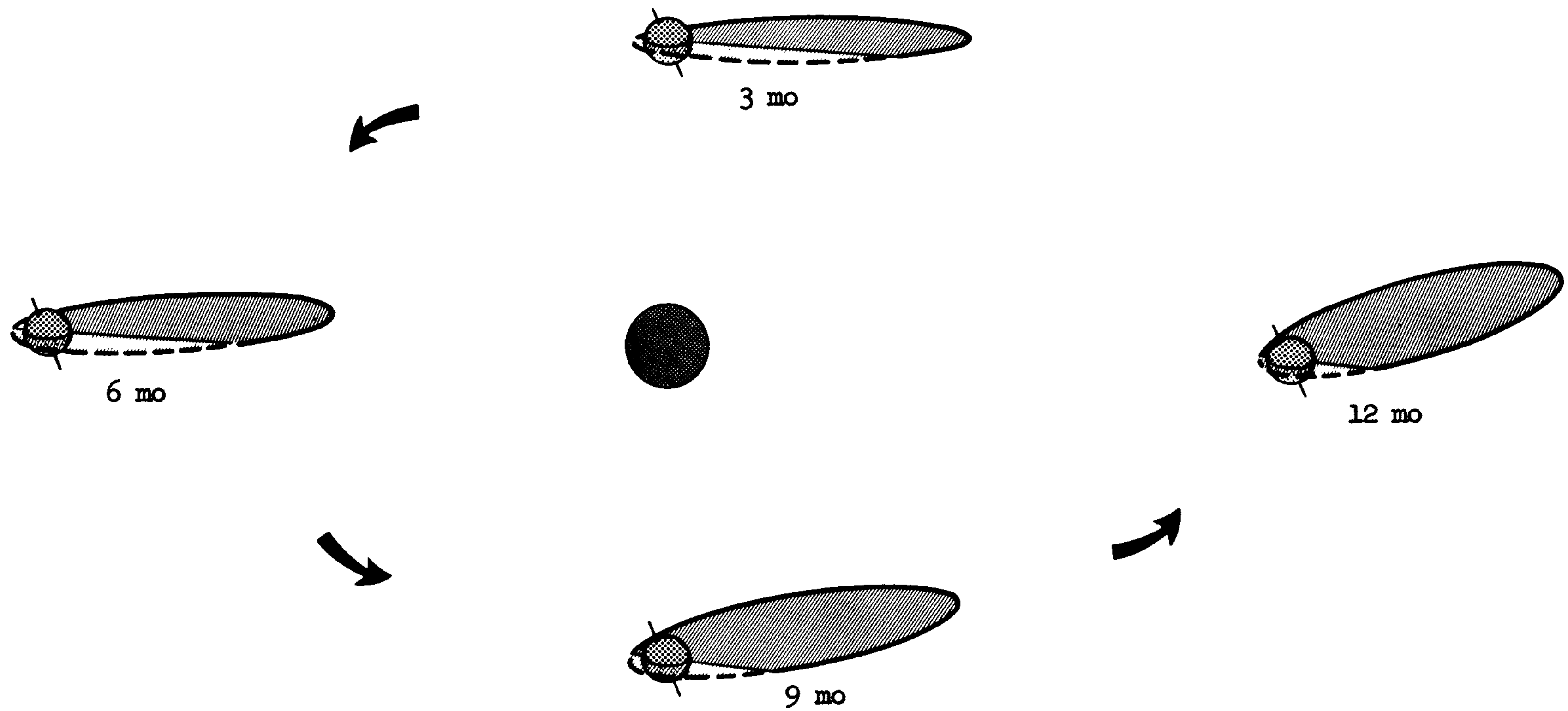

Fig. 4--1.5 a_e/15 a_e orbit at 3, 6, 9, and 12 months after being launched into the ecliptic plane at the summer solstice with perigee on the earth-sun line when the earth was in the 12-mo position. The initial orientation is not shown. The ecliptic intersects the orbit plane along the straight line and the dashed part of the orbit is below the ecliptic.

ring is not well known and probably varies with solar activity. For our purposes we will assume that a satellite going 7 earth radii from the earth's center will traverse interesting regions of the ring.

ELLIPTIC ORBIT INITIALLY IN ECLIPTIC PLANE (PERIGEE DISTANCE 6878 km, APOGEE 7 a_e)

The fourth orbit to be considered is an elliptical one with a perigee distance of 6878 km or 500 km above the earth's surface and an apogee distance of 7 earth radii or 6 earth radii above the earth's surface launched into the ecliptic plane with perigee on the earth-sun line.

A satellite in this orbit could then make observations on the solar "windward" and "leeward" sides of the earth at certain times during the year. It would start beneath the lower belt, pass through it and the slot between the belts, then through the outer belt and beyond, thus giving frequent readings on all these regions as shown in Fig. 5. Since the period of this satellite would be roughly one-fourth the period of the larger elliptic orbit discussed earlier, changes occurring in the regions of the belts following solar activity could be more promptly reported with this one.

With a period of 11.4 hours 769 revolutions would occur during a year. If data were taken at the rate of 432 readings per revolution as indicated previously, 322,000 readings would be taken during a year, or one every one minute and 38 seconds.

The stability of this orbit against solar and lunar perturbations would be greater than for the larger elliptic one described earlier. However, care must still be taken to achieve the proper conditions at launch so that the perigee distance will remain more or less constant.

Perturbations from the earth's oblateness would cause the line of nodes to regress 118 deg during a year, while the perigee would advance 206 deg. These changes cause the orientation of the orbital plane in respect to the ecliptic plane to vary as shown in Fig. 6.

Magnetic and energetic particle data for 30-40 magnetic storms during a year from a satellite in this orbit could be measured advantageously. If continuous operation were not desirable and if system

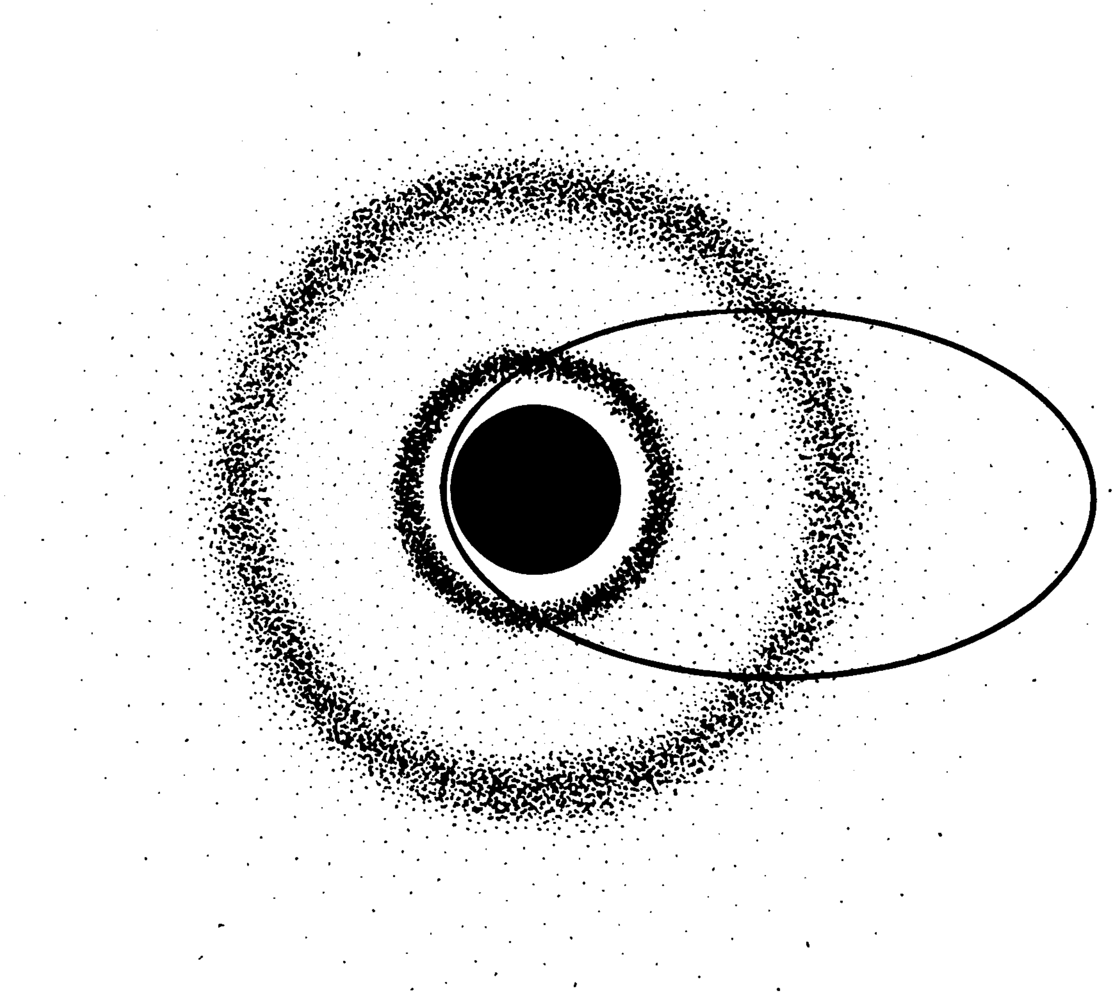

Fig. 5--Manner in which 6878 km/7 a_e orbit in ecliptic plane passes through belts about the earth

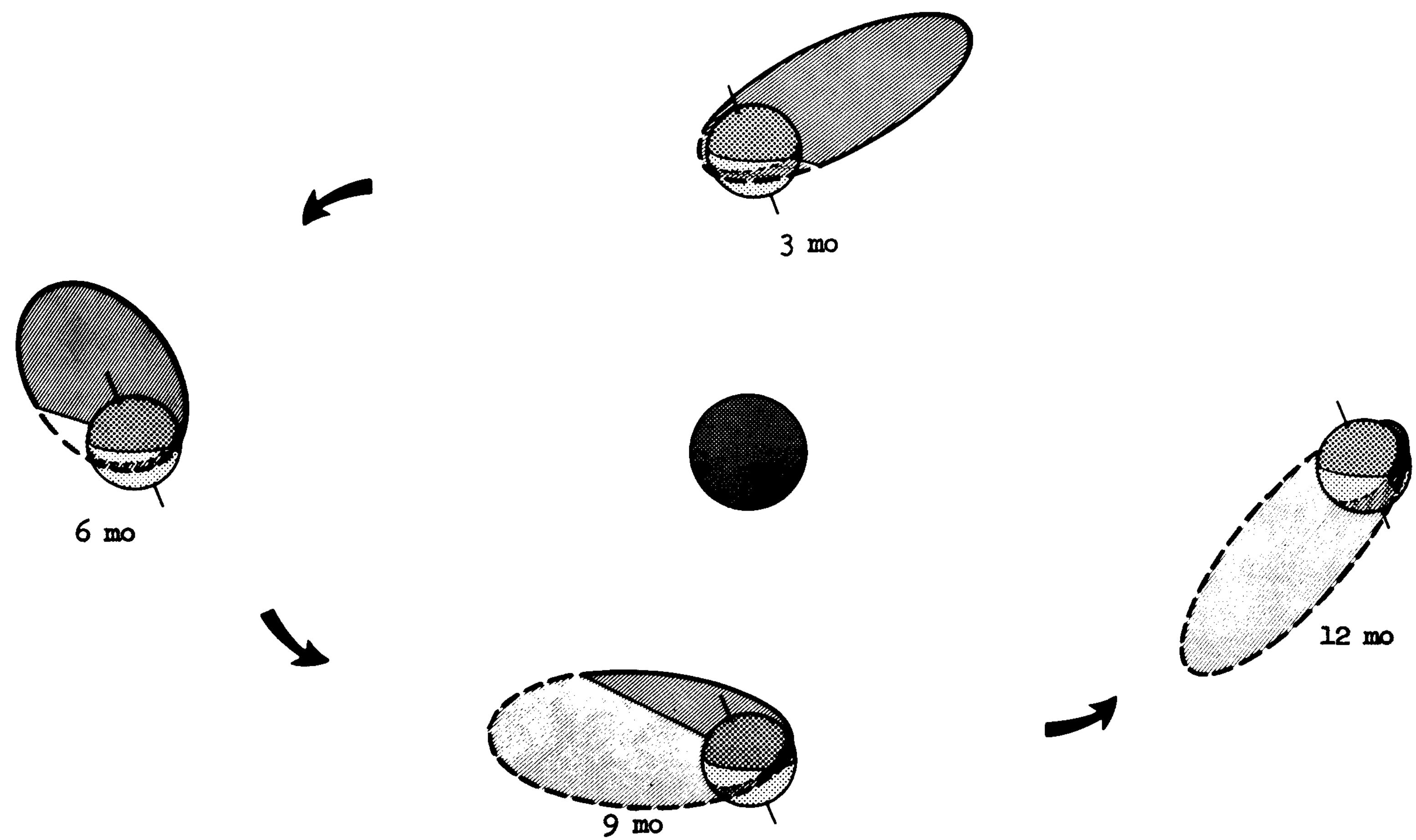

Fig. 6--6878 km/7 a_e orbit at 3, 6, 9, and 12 months after being launched into the ecliptic at the summer solstice with perigee on the earth-sun line when earth was in the 12-mo position. The initial orientation is not shown. The ecliptic intersects the orbit plane along the straight line and the dashed part of the orbit in below the ecliptic.

reliability could be maintained at a level permitting intermittent operation, this satellite, as a dormant sentinel in orbit, could be awakened on command to take observations of special interest and then returned to a dormant state during periods when the sun was quiescent.

ELLIPTIC ORBIT INITIALLY IN ECLIPTIC PLANE (PERIGEE DISTANCE 7078 km, APOGEE DISTANCE 2 a_e)

The fifth orbit to be considered is elliptical with a perigee distance of 7078 km and an apogee distance of 12,750 km (2 a_e). This orbit has a perigee altitude of about 700 km above the earth's surface and an apogee altitude of one earth radius. The satellite will pass beneath the lower Van Allen belt and out beyond the usual position of the maximum. Hence, it will serve as an excellent monitor for this belt. This is the main reason for considering it.

If the orbital plane were initially in the ecliptic with perigee on the earth-sun line, the sampling would be approximately as shown in Fig. 7. Perturbations from the earth's oblateness would cause the argument of perigee to advance 360 deg just about every 90 days, while the line of nodes would regress about 213 deg during the same interval. These perturbations would cause the orbital plane to assume the positions shown in Fig. 8 during the year. Lunar and solar perturbations would produce further variations in the orbit. However, with proper launch conditions, these perturbations should not be serious during one year.

A satellite in this orbit would permit no observations in the polar regions of the earth but the equatorial extent of the belt would be well sensed. If there were 432 readings per revolution as suggested for the other satellites, there would be 1.39 million readings per year, or one every 22.7 seconds.

POLAR ELLIPTIC ORBIT (PERIGEE DISTANCE 7078 km, APOGEE DISTANCE 2 a_e)

The sixth and last orbit to be considered is similar to the preceding one except it contains the earth's axis, and perigee is initially on the earth's axis of rotation. This satellite would sense the very interesting regions in the vicinity of the earth's poles as shown in Fig. 9. Here observations would be available from the auroral region,

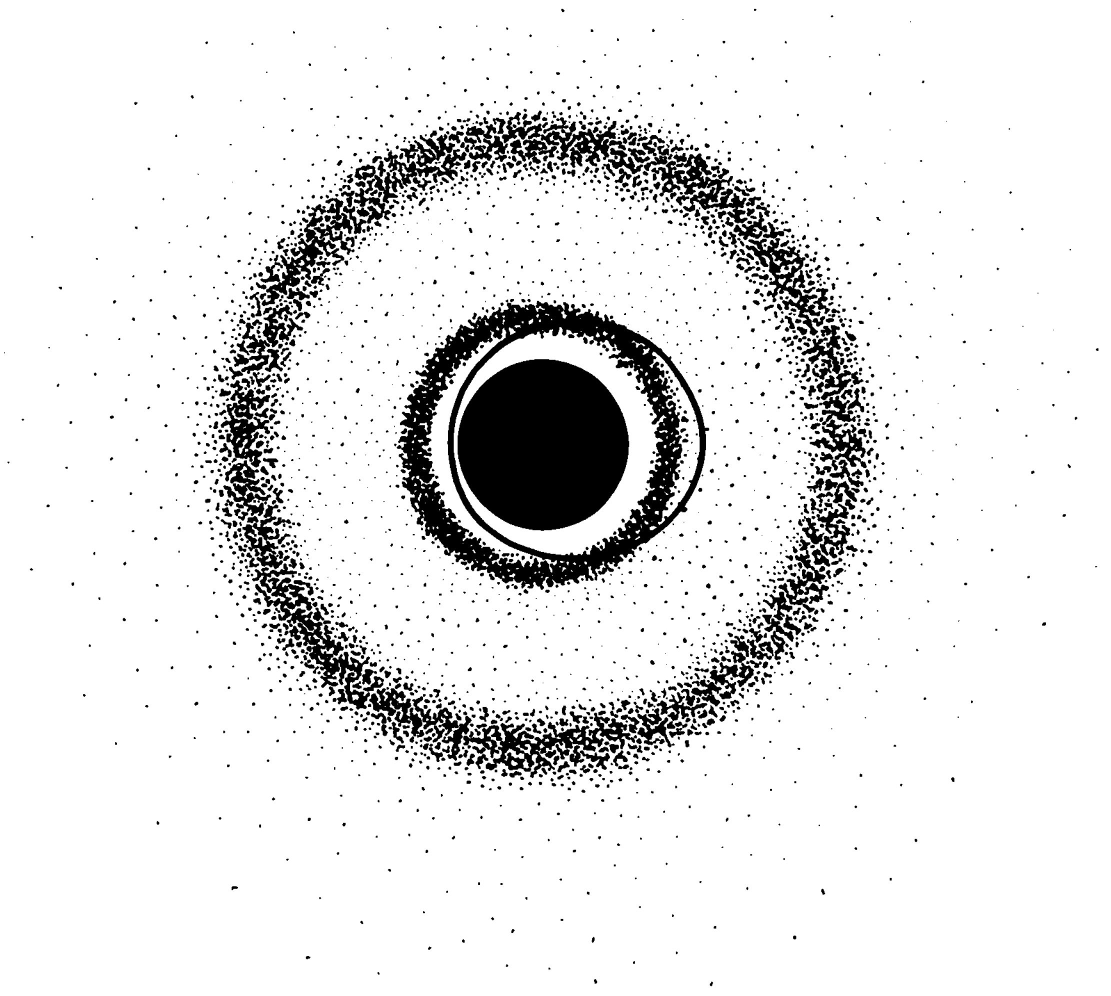

Fig. 7--Manner in which 7078 km/2 a_e orbit in ecliptic plane passes through belts around the earth

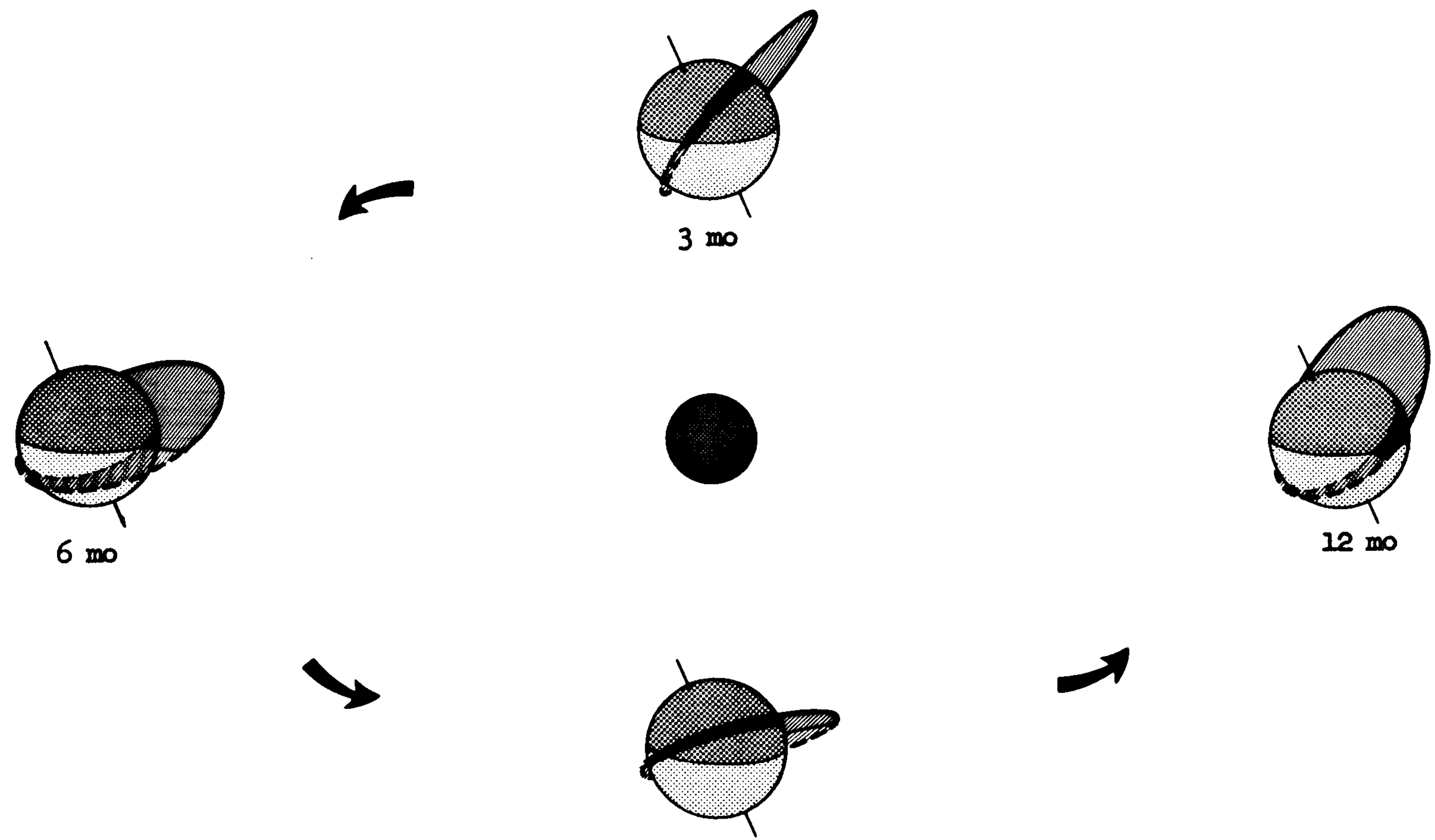

Fig. 8--7078 km/2 a_e orbit at 3, 6, 9, and 12 months after being launched into the ecliptic plane at the summer solstice with perigee on the earth-sun line when the earth was in the 12-mo position. The initial orientation is not shown. The ecliptic intersects the orbit plane along the straight line and the dashed part of the orbit is below the ecliptic.

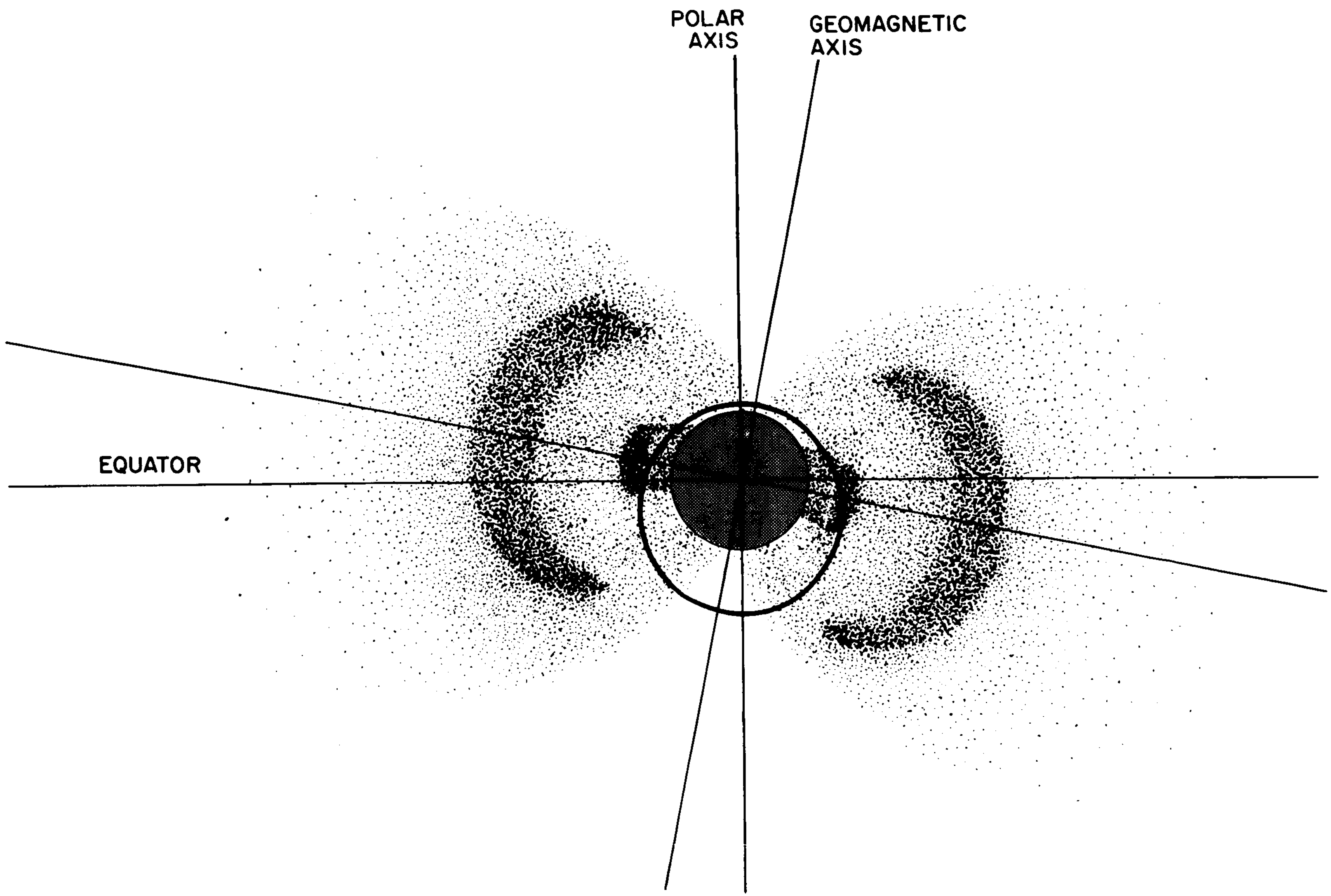

Fig. 9--Manner in which 7078 km/2 a_e polar orbit passes through belts around the earth

which shows some interesting responses to solar variations.

Because of the different initial inclination to the equatorial plane, the oblateness perturbations will be different than for the preceding orbit. With an inclination to the equator of 90 deg there should be no regression of the nodes and hence the orbital plane will maintain a fixed orientation during the year as was the case with the other polar orbits. However, the argument of perigee will regress, not advance, about 120 deg during each 90 day interval. Figure 10 shows the orbital orientation in the orbit plane at four times during the year when only oblateness perturbations are considered.

During the year readings will be taken at all latitudes from pole to pole and at altitudes from 700 km to one earth radius above the earth's surface. Also a complete range of longitudes measured from the earth-sun line will be covered during the year.

This satellite also could be kept in a dormant state most of the time and awakened on command to take observations intermittently. It would provide an exceptional opportunity to measure the geomagnetic secular change, and hence to obtain indications of changing fluid motions within the earth's central core. The good coverage possible by such a satellite, both in time and space, would make this a valuable method for undertaking a study of a major geophysical problem of the earth.

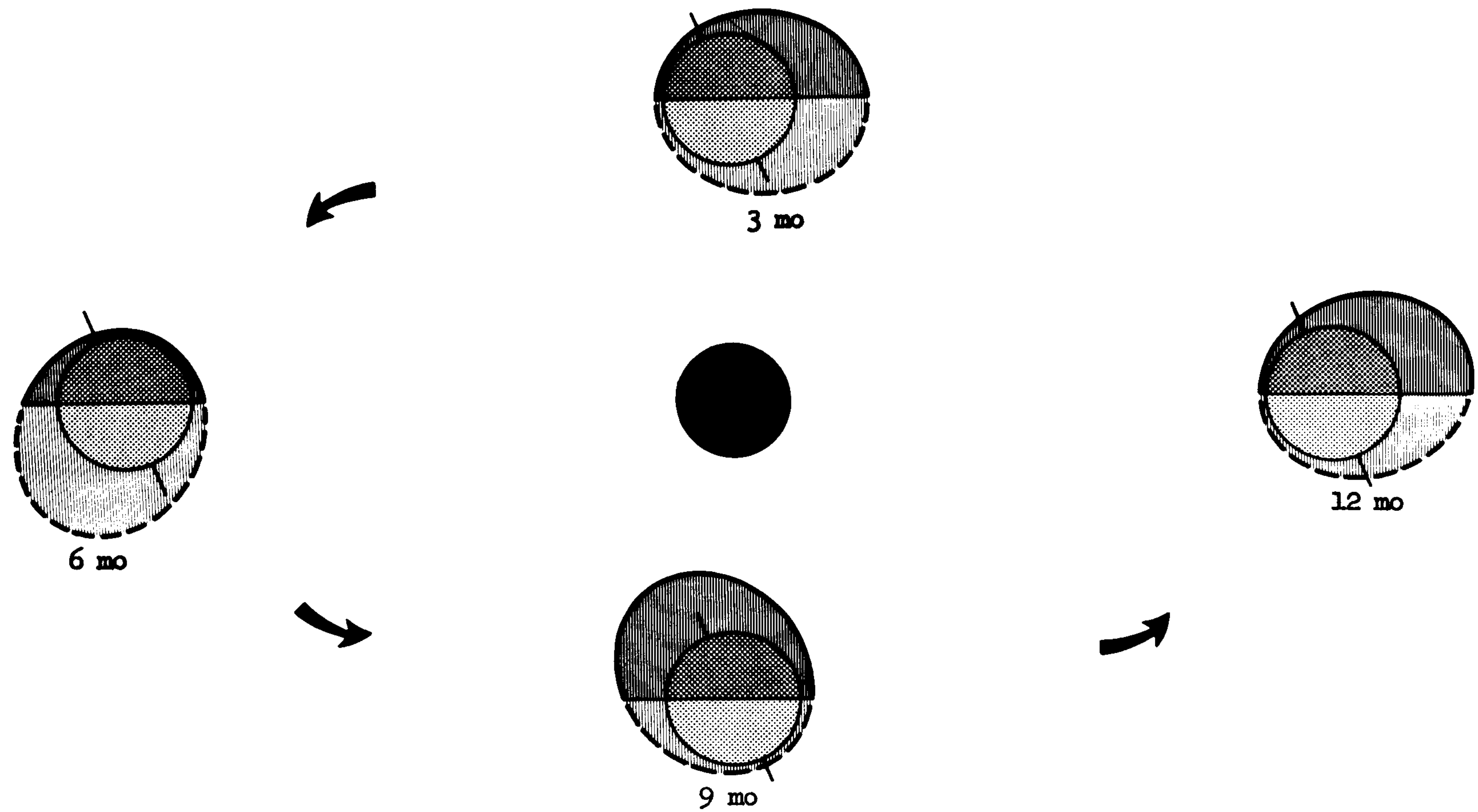

Fig. 10--7078 km/2 a_e polar orbit at 3, 6, 9, and 12 months after being launched at the summer solstice with the orbit plane containing the earth-sun line and perigee on the earth's axis above the South Pole. The initial orientation is not shown. The ecliptic intersects the orbit plane along the straight line and the dashed part of the orbit is below the ecliptic.

IV. CONCLUSIONS

Satellite-borne magnetometers and counters offer an exceptional opportunity for the description, mapping, and study of the earth's magnetic field and its charged particle population from ground level to nearby space, as a function of time. These survey data are of importance in navigation, in engineering, and in the scientific applications of particles and fields, geomagnetism and aeronomy, and other related areas of solar-terrestrial relationships. Proper selection of orbits is necessary to provide good coverage of the earth's magnetic field during a year's operation.

Possibly useful satellite orbits for the World Magnetic Survey include:

1. A circular polar one with a radius of 6898 km (520 km), which would extend and improve charts of the geomagnetic field at ground level and in nearby space and provide valuable new data on polar aurora, magnetic disturbances, and polar radio blackouts.

2. Another operated simultaneously in a circular polar orbit at as high an altitude as conveniently possible (at least one or two thousand kilometers above the 500 km satellite), which would notably sharpen and extend results from other means and afford a unique opportunity for detailed study of the inner Van Allen radiation belt.

3. A very elliptical one more or less in the ecliptic plane with a period permitting useful definition of the effects of the solar wind at different distances from the earth.

4. An orbit of shape similar to that in (3) above but having a smaller semi-major axis and being more or less in the plane of the ecliptic, which will permit more frequent monitoring of the charged belts and the earth's field during periods of rather rapid changes.

5. An elliptic orbit initially in the ecliptic plane that will sample the inner Van Allen belt repeatedly. Such a satellite will have a perigee altitude of 700 km and an apogee altitude of one earth radius. During the course of a year this satellite will provide much information on the variations of the magnetic field and particle populations as influenced by solar activity on the sunlit and dark sides of the earth.

6. An orbit similar to (5) but having the orbit plane oriented to contain the earth's axis of rotation. This would permit excellent monitoring of the interesting regions of the Van Allen belts near one of the earth's poles where the horns of the belt drop down to low altitudes and probably undergo rapid and perhaps rather violent fluctuations during periods of strong solar activity.

7. If this satellite remained aloft and intermittently active on command for a decade or so, there would be an exceptional opportunity to measure the geomagnetic secular change and hence to obtain indications of changing fluid motions within the earth's central core. The good coverage possible by such a satellite, both in time and space, would make this a valuable method for undertaking study of a major geophysical problem of the earth.

A summary of data on the orbits is given in the table. Also included are comparable data for the Soviet satellite launched in March, 1962.

SUMMARY DATA ON ORBITS

Orbit	Period	Orbits per Year	Readings per Orbit[a]	Readings per Year	Time Interval between Readings	Perturbations of Orbit Due to Sun, Moon, and Earth Oblateness[b]
6878 km radius (circular)	1.58 hr (95 min)	5540	432	2.4×10^6	13.2 sec	Insignificant
10 a_e radius (circular)	44.5 hr	197	432	85,100	6.2 min	Very small
1.5 a_e perigee 15 a_e apogee	33.4 hr	262	432	113,000	4.6 min (average)	Depends on relative positions of sun, moon, and earth at launch
6878 km perigee 7 a_e apogee	11.4 hr	769	432	332,000	95 sec (average)	Depends on relative positions of sun, moon, and earth at launch
7078 km perigee 2 a_e apogee	2.72 hr	3219	432	1.39×10^6	22.7 sec (average)	Depends on sun, moon, earth relative positions at launch
USSR satellite launched mid-March 1962 217 km/980 km	1.61 hr (96.5 min)	5451	432	2.35×10^6	13.4 sec	Nodes regress 4.8 deg and perigee advances 4.2 deg per day

[a] Number matches that for 100 km spacing along orbit of 500 km satellite.

[b] Earth oblateness will cause a regression of the line of nodes for direct orbits and an advance of the line of nodes for retrograde orbits. This motion varies directly as the cosine of the angle of inclination of the orbital plane to the earth's equator. At the proposed 82 deg inclination for the POGO satellite orbit, the line of nodes will regress approximately 360 deg in one year.

REFERENCES

1. Vestine, E. H., "The Survey of the Geomagnetic Field in Space," Trans. Amer. Geophys. Union, Vol. 41, 1960, pp. 4-21.

2. Vestine, E. H., Instruction Manual on World Magnetic Survey, Monograph No. 11, International Union of Geodesy and Geophysics, Paris, August, 1961.

3. Heppner, J. P., et al., "Project Vanguard Magnetic Field Instrumentation and Measurements," First International Space Science Symposium of COSPAR, Nice, France, January 1960.

4. Heppner, J. P., et al., "Explorer 10 Magnetic Field Measurement," Jour. Geophys. Res., Vol. 68, 1963, pp. 1-46.

5. Heppner, J. P., T. L. Skillman, and J. C. Cain, "Contributions of Rockets and Satellites to the World Magnetic Survey," Second International Space Science Symposium of COSPAR, Florence, Italy, April 1961.

6. Sonett, C. P., A. R. Sims, and I. J. Abrams, "The Distant Geomagnetic Field," Jour. Geophys. Res., Vol. 67, 1962, pp. 1191-1207.

7. Kalinin, Yu. D., Geomagnetism and Aeronomy, Vol. 1, 1961, pp. 618-19.

8. Smith, E. J., Space Technology Laboratories, private communication.

9. Space Technology Laboratories, Flight Performance Handbook for Orbital Operations, Raymond W. Wolverton, ed., September, 1961.